sible to calculate differences in valve position as large as 20%. Following design procedures for determining cavitation (13,14), torque (1), maximum possible flow (9), and transients (16) can result in errors and differences as large as 150–200%.

Therefore, it is recommended that the testing of control valves should carefully consider the effect of pipe friction between the test pressure taps; and pipe friction should be accounted for in the testing of control valves that have C_v/D^2 values greater than 20. Also, it is recommended that tests for the flow coefficient should use pressure taps located at a minimum of 1 diam upstream and at 10 diam downstream of the valve.

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ACCEPTABLE WALKING DISTANCES IN CENTRAL AREAS

By Prianka N. Seneviratne[1]

(Reviewed by the Urban Transportation Division)

ABSTRACT: Pedestrian walking distances in a central business district are mostly dependent on the arrival mode in that central business district and the layout of the transportation network on which these modes operate. Changes to the existing pattern of operations, in terms of the location of new transportation facilities or relocation of existing facilities, can have a significant impact on walking distances. However, often the prime concern has been the impact of these changes on the flow of traffic, with little or no emphasis on the pedestrians. As opposed to arbitrarily derived acceptable walking distances suggested by some researchers, an approach based on findings from a series of surveys conducted in Calgary, Alberta, Canada, is proposed. A set of characteristics that influence the distribution of walking distances is identified. Depending on the form of the distribution, the "critical" distance that would be acceptable to a group of people can be derived using simple calculus. The critical distance will be the distance at which the rate of change of the slope of the frequency distribution of the walking distance for that group of people is greatest. Since the walking distance distributions indicate the propensity to walk, they indirectly represent the actual feelings of the people. This approach also facilitates decisions regarding locations, even where information regarding walking habits is scarce or unavailable. The application of Bayesian statistical decision theory enables one to estimate the appropriate distribution and the critical distance associated with it.

INTRODUCTION

A major problem faced by most city engineers and planners is determining the "optimal" locations for parking facilities, transit stops and pedestrian facilities, such as overpasses, crosswalks or bridges. This problem is no less severe in smaller cities than in larger cities, anywhere around the globe.

It is obvious that the problem is caused by the conflicting interests of planners, engineers, motorists, operators of transit systems, and their users, i.e., passengers. For instance, passengers and motorists become pedestrians, with a main objective, especially during the morning peak, of reaching their destinations as quickly as possible. During the afternoon peak hours, they want to get to their respective vehicles as quickly as possible and have a quick ride home.

Ideally, motorists would like to park adjacent to their ultimate destinations, and the transit authority would like to locate its stops or terminals as close as possible to the major generators. Furthermore, these groups also expect easy vehicular access to and from the parking lots or transit stops onto the main arterials that will take them to their respective destinations.

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In the quest for solutions that would satisfy these conflicting needs, most local authorities have preoccupied themselves with deriving methods that would alleviate traffic congestion. For example, parking control, traffic management schemes, "pedestrian-only" areas and transit malls are some measures adopted in various cities. However, those responsible for these schemes have rarely examined the needs of pedestrians with regard to walking distances.

This paper reports some findings on factors affecting pedestrian walking distances, and suggests a means of determining acceptable walking distances which, in turn, could be incorporated in the facility location process.

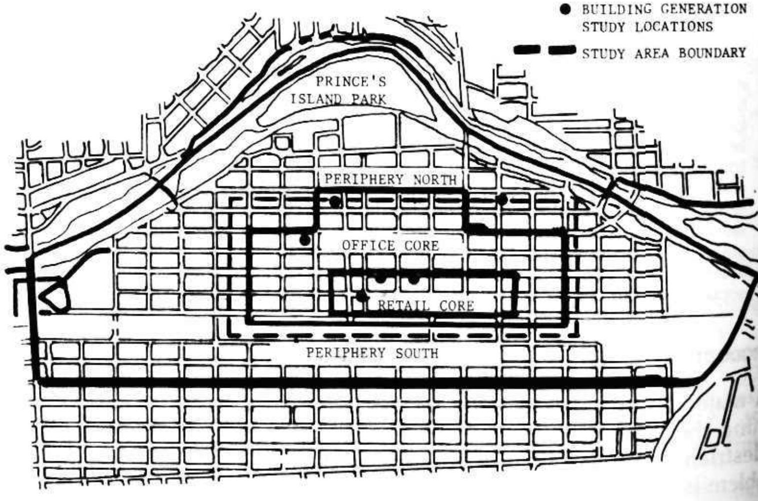

FIG. 1.—Downtown Calgary Pedestrian Study Area Boundaries

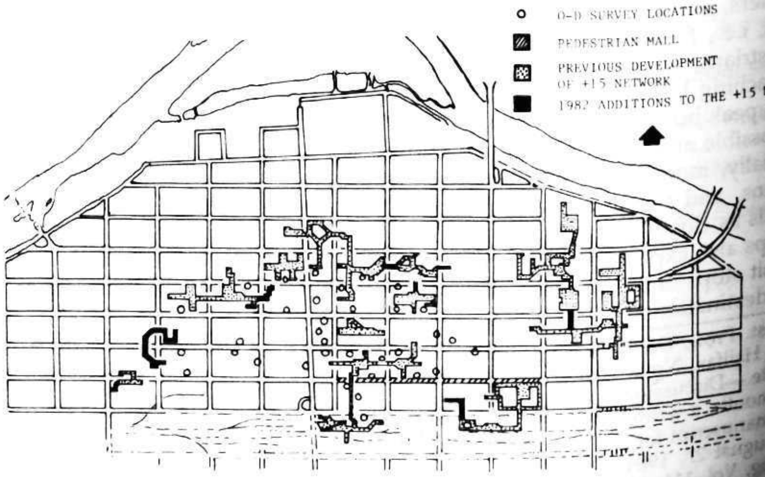
○ O-D SURVEY LOCATIONS
▨ PEDESTRIAN MALL
PREVIOUS DEVELOPMENT OF +15 NETWORK
■ 1982 ADDITIONS TO THE +15 NETWORK

FIG. 2.—OD Survey Locations and Plus-15 System

From the pedestrian's point of view, one means of determining the optimal location of facilities is based on the frequency distribution of walking distances. These distributions provide some information about people's propensity to walk. Depending upon the form of the distributions, a decision can be made regarding the maximum acceptable walking distances and, thus, the appropriate locations.

DATA COLLECTION

The suggestions and conclusions in this report are based on a series of surveys conducted in the central business district (CBD) of Calgary, Alberta, Canada. The CBD of Calgary has a daytime working population of approximately 82,000 and a residential population of 9,500. The study area shown in Fig. 1 consists of approximately 75% of the land area and buildings given in Table 1.

An origin-destination (OD) survey provided information on pedestrian walking distances and the factors affecting the choice of route. A total of 36 locations shown in Fig. 2 were covered in nine days by six interviewers who intercepted pedestrians at random at entrances to buildings, transit stops, midblock sidewalks and elevated walkways. The time periods in which the surveys were conducted were 7:30–9:00 and 10:00–11:30 a.m., and 12:30–1:30, 2:30–3:30, and 4:00–5:00 p.m. These time periods covered most types of trips, e.g., commuter, shopping, and business trips, during peak and off-peak periods; they also made sufficient rest periods for the interviewers possible. A total 2,900 interviews were obtained, 2,685 of which were eventually usable.

The information related to walking distances was obtained by requesting the respondents to indicate the path taken between their origin and final destination within the CBD on an elaborate 1 in.:400 ft map of the study area. In addition, the respondents were asked to select the factor that would best describe their reason for selecting that path. For origins

TABLE 1.—Downtown Calgary Statistical Overview: 1981

Employment population	82,200
Residential population	9,500
Area	15 sq miles (39 km^2)
Office space	19 million sq ft (1.77 million m^2)^a
Roadway lanes into downtown	30
Downtown main-line bus routes	20
Downtown express bus routes	15
LRT routes to downtown	1
Long-term parking stalls	22,000
Short-term parking stalls	11,000
Percent of downtown area assigned for parking	14
Percent of area used by traffic lanes (right of way)	23

^{a}Figures from A. E. LePage Report on Calgary Office Space Statistics, March, 1982.

Sources: Ref. 10.

and destinations outside the study area, the respondents were asked for the nearest intersection, and later measured from the base map. There is approximately ±5% variance in the distances obtained from the questionnaire, since distance could vary slightly depending on the side of the street the respondent used.

The data were analyzed using the Statistical Package for Social Sciences (SPSS), which enabled a wide range of cross tabulations to be done and frequency distributions to be obtained for all variables considered.

VARIABLES INFLUENCING WALKING DISTANCES

Regular visitors to a CBD, especially CBD employees, seem to adopt a routine path, e.g., between the parking lot and their place of work. Most of the time this routine path turns out to be the shortest path, at least in the case of Calgary (10). This could be the case in other cities as well.

These walking patterns are obviously a function of the location of the transportation facilities, i.e., the location of bus stops, parking facilities and crosswalks, as well as of the destinations. They will, therefore, give rise to a wide range of walking distances, depending on the type of trip, its purpose and the time of day. The distribution of walking distances is a useful guide to planning authorities, e.g., when formulating transportation plans. First, even in a growing city, the distributions have to remain fairly constant. For instance, major traffic management schemes or reductions in the supply of parking can be costly to both pedestrians and property owners in the area. In Central Liverpool, England (2), the disadvantages of a pedestrianization scheme, e.g., reduced accessibility, far outweighed the benefits, in the people's opinion. Secondly, a transportation plan can have an impact of great magnitude on walking distance, in terms of the number of persons affected. For example, if the walking distance distributions for trips from the parking area to the place of work are known, the number of people who may be influenced by plans to remove or add parking stalls at a particular location could be determined from the change in walking distance.

As mentioned earlier, the impact of such plans would vary, depending on several factors. Five such factors identified during the Calgary study are outlined in the following to illustrate the way such plans would affect each of them.

TABLE 2.—Statistics Related to Distributions of Walking Distance from Work

Statistic (1)	Trip Type					
	To shopping (2)	To parking (3)	To bus (4)	To LRT (5)	To eat (6)	To home (7)
Mean	1,096 ft (334 m)	1,136 ft (346 m)	820 ft (250 m)	940 ft (287 m)	922 ft (281 m)	2,110 ft (643 m)
Median	1,015 ft (309 m)	1,057 ft (322 m)	705 ft (215 m)	868 ft (265 m)	913 ft (278 m)	2,543 ft (775 m)
Mode	650 ft (198 m)	850 ft (259 m)	550 ft (168 m)	550 ft (168 m)	350 ft (107 m)	3,125 ft (953 m)
Standard deviation	476 ft (145 m)	496 ft (151 m)	384 ft (117 m)	412 ft (126 m)	495 ft (151 m)	538 ft (164 m)
Number of cases	204	131	625	261	160	46
Percent of total sample	7.6	4.9	23.2	9.7	6.0	1.7

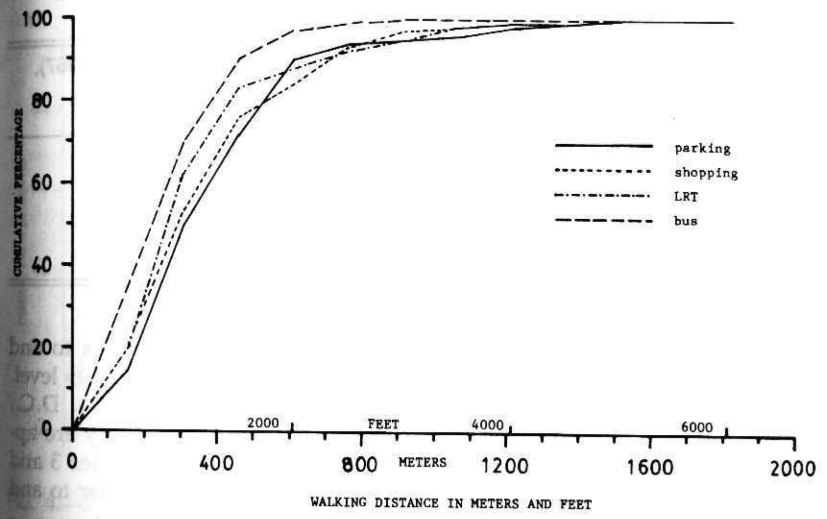

FIG. 3.—Cumulative Frequency Distributions of Walking Distance from Place of Work

Trip Type.—The trip types are defined in relation to land use at the origin and final destination. For instance, a CBD employee who arrived in the CBD by bus or returned home by bus would be defined as a bus-to-work trip.

A total of 31 different trip types were identified. Only the ones with fairly large sample sizes are considered here. A statistical summary of walking distances related to six work-based trips (i.e. with one end of the journey at the place of work) are shown in Table 2 and the distributions are shown in Fig. 3. These trips make up over 50% of the total trips.

TABLE 3.—Mean Walking Distance to or from Mode of Arrival in Downtown

Mode (1)	Calgary distances (1982), in ft (m) (2)		Toronto distances (1967), in ft (m) (3)	
LRT	940	(278)	—	—
Auto driver	1,136[a]	(346)	1,558	(475)
Bus	820	(250)	977[b]	(298)
Auto passenger	—	—	1,056	(322)
Subway	—	—	1,135	(346)
Walk home	2,110	(643)	4,039	(1,231)
Commuter rail	—	—	2,086	(636)
All modes	1,100	(335)	1,211	(369)

[a] Includes auto passengers.
[b] Includes street cars.

TABLE 4.—Comparison of Walking Distances by Cities

Trip type (1)	Calgary distances (1982), in ft (m) (2)	Chicago distances (1967), in ft (m) (3)
To work	965 (294)	970 (296)
To home	2,110 (642)	1,100 (335)
To shop	1,096 (334)	900 (274)
To business	860 (262)	980 (299)
All-purpose	1,100 (335)	970 (296)

The differences between each of the mean walking distances to and from the main modes of transportation are significant at the 0.05 level. Compared to transit-related walking distances in Washington, D.C., studied by Petersen (6), the mean walking distances in Calgary are approximately twice as great. On the contrary, as seen from Tables 3 and 4, the corresponding distances in Calgary are sometimes similar to and sometimes different from those of Toronto (3) and Chicago (8).

This confirms that walking distances are not strictly a function of city size or the density of development, but are related to the transit and road network as well, and the overall transportation policies of a city. Note, however, that Calgary data relate to 1982, while the Toronto and Chicago studies were done in the late 60's. Nevertheless, for Calgary, the change in walking distance distributions for bus-to-work trips between 1978 (4) and 1982 is insignificant.

Trip Purpose.—This is defined according to the primary purpose of one's visit to the CBD. The majority of the sample analyzed consisted of either employees in the CBD or people visiting for business purposes. A fair proportion of tourists and shoppers was also sampled during off-peak periods.

The trip purpose is a very important element in determining pedestrian requirements. This element and the requirements can vary significantly, depending on the city. For example, Calgary is a major business center for the oil industry in Canada. Therefore, a high proportion of people visit the CBD for business purposes. Unlike New York, New York, or London, England, the number of tourists is small.

The needs fo the business people usually differ from those of CBD employees. For instance, the former group prefers short-term parking near the destination, while employees would accept slightly longer walking distances and require long-term parking.

Visitors, on the other hand, are often transit users, or walk longer distances. In Calgary, shoppers walked an average of 1,000 ft (305 m) while employees walked 965 ft (294 m). In this instance the difference is not significant, since more than 70% of the shoppers were transit users. The transit network is heavily concentrated in the retail core (the shopping area).

From the cumulative distribution of walking distances in Fig. 4, one can see how the changes depend on trip purpose. For example, if short-term parking is reduced or insufficient to meet the demand, business people are likely to be severely affected.

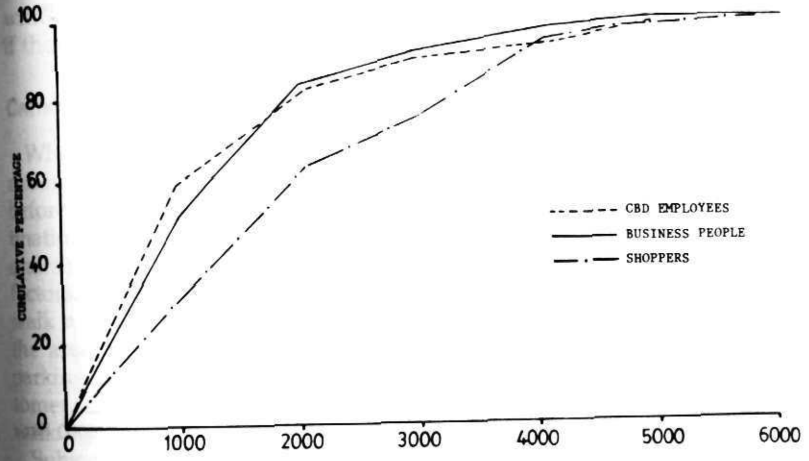

FIG. 4.—Cumulative Frequency Distributions of Walking Distance for Different Trip Purposes

Age and Sex of Pedestrians.—The mean walking distance of males and females in the three age groups considered differed significantly at the 0.05 level of significance. Similar differences were noted in New York by Shoppert & Herald (9), as shown in Table 5. However, no significant differences between the age groups for either sex are evident from the distributions of walking distances. The three cumulative frequency distributions of males in the three age groups almost overlap, and so do the female distributions. Therefore, it is reasonable to assume that the difference is by sex and not by age.

Geographic Location.—Different sites within the same CBD can have a significant influence on walking distances. Walking distances could vary from one location to the next, especially in a large city with a large

TABLE 5.—Mean Walking Distances, by Age and Sex

Group (1)	Age group (yr) (2)	Percent of Trips		Mean (ft)[a]	
		Calgary (1982) (3)	New York City (1971) (4)	Calgary (5)	New York City (6)
Male	15–30	14.5	10.2	1,000 (463)	1,502
	30–50	30.0	35.1	1,075 (475)	2,044
	50+	5.6	6.5	1,185 (582)	1,711
Female	15–30	24.4	28.8	850 (424)	1,608
	30–50	21.3	14.6	915 (430)	1,443
	50+	4.3	4.2	880 (416)	1,244
Male	Overall	49.1	51.8	1,050 (470)	1,900
Female	Overall	50.9	48.2	750 (382)	1,520

[a] Figures in parentheses represent the standard deviation.
Note: 1 ft = 0.305 m.

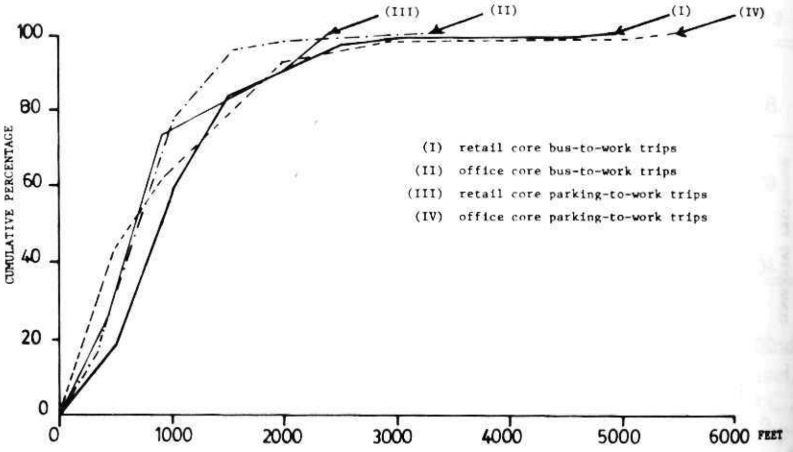

FIG. 5.—Cumulative Frequency Distribution of Walking Distance at Different Locations

CBD. The differences in average walking distances between cities, mentioned earlier, could also be attributed to the characteristics of the sites within the CBD were the surveys were conducted.

These differences can be clearly seen from the Calgary study. The 36 interview locations shown in Fig. 2 were categorized in five groups for analytical purposes. The five groups were the retail core, the office core, the pedestrian-only mall, and the "plus 15" (elevated walkways 15 ft above the streets and sidewalks) systems in the office and retail cores.

As shown in Fig. 5, the rate of change of the number of pedestrians with respect to walking distances in the retail core is quite different from that of the office core. The difference also increases or decreases with the trip type or trip purpose.

Time of Day.—The trip type and trip purpose of the respondents changes with the time of day. For example, in the morning peak hours, most people are employees, while in the morning off-peak hours, the majority are shoppers, visitors and business people. Since the walking patterns of these groups are different, there will be differences in the distributions.

These distributions may be used as guides for implementing parking policies. For example, there could be on-streeet parking closer to the retail core during off-peak periods, or larger spacing for bus stops during the peak hours because more people would accept relatively longer walking distances.

Cost of Parking.—This variable was not considered in the Calgary study. However, several researchers found it to be a significant factor affecting walking distance. It is a complex variable to analyze. First, the question of the value of time and other intangible costs arises. Secondly, the type of demand or the trip purpose will determine the degree to which walking distances are influenced by parking costs. For instance, if a parking location caters to business people, the rate of change in walking distance with respect to cost would remain the same to a much higher cost than if the location catered to shoppers or regular employees.

CRITICAL WALKING DISTANCES

Whatever the characteristic considered, there would be a "critical" or maximum distance that a person in a particular category would walk before finding an alternative route or a facility closer to his or her destination. These critical distances have been derived subjectively by several sources, but without much regard to the aforementioned types of factors. For instance, it has been suggested that CBD workers would walk a maximum of approximately 2,000 ft (610 m) if parking costs in the area are attractively low (5). There is no reference to the range of parking costs that may be considered attractive, or to the type of customer. Other researchers have specified average or median reasonable walking distances (7).

Subjectively derived critical distances may lead to undesirable locational decisions. For example, in the CBD of Halifax, Nova Scotia, there is somewhat of a surplus of off-street parking within the median walking distance from most major generators. However, a high number of parking tickets is issued by the City Police Department because of the shortage of on-street, short-term parking spaces. This may be because the aforementioned factors were not considered during the planning stages. In other words, the types of trips generated by the CBD were not properly investigated prior to supplying the off-street parking. From one point of view, the off-street parking was within acceptable walking distance, but, at another level, visitors and business people like much shorter walking distances or on-street parking closer to their destinations. Furthermore, the bases for selecting the mean or median walking distance as the acceptable distance are not clearly evident from the literature.

Three probability distributions were fitted to the observed walking distance data from Calgary. The three distributions considered were normal, lognormal, and gamma. In most instances, the gamma distribution fit the data best, as indicated by the chi-square values in Table 6, partly because of the highly positively skewed distributions shown in Fig. 6.

If, by examining the goodness of fit, the form of the probability distribution function can be determined from the available data, one could easily evaluate the critical walking distance for a given trip type.

For instance, cumulative frequency distributions, such as those shown

TABLE 6.—Parameters of Distributions Fitted to Bus-to-Work Trips in Calgary

Distribution (1)	Parameters (2)	Goodness-to-fit (3)
Normal	Mean = 819.29 ft Standard deviation = 571.33 ft	$X^2 = 25$ $d.f = 2$
Gamma	$m = 1/398.42$ $R = 2.06$	$X^2 = 5.8$ $d.f = 3$
Lognormal	$\alpha = -6.953$ $\beta = 395.07$	$X^2 = 25.7$ $d.f = 2$

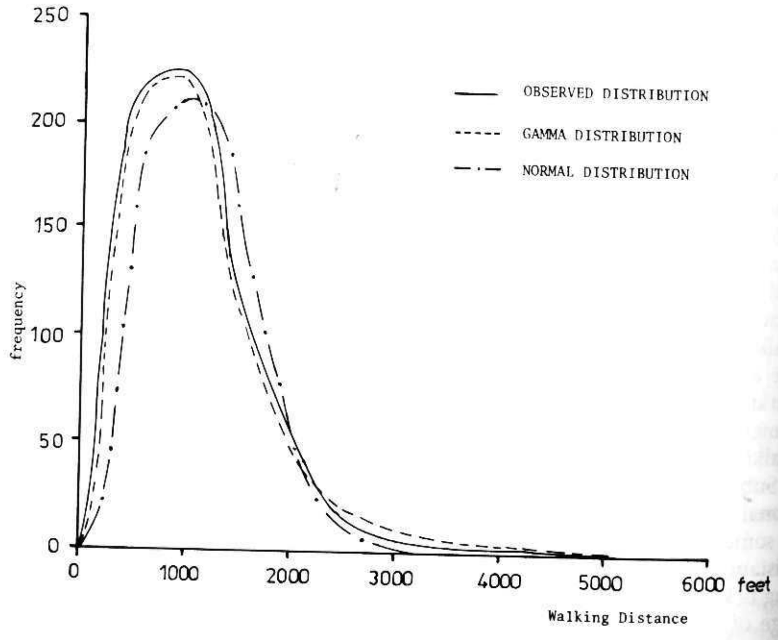

FIG. 6.—Probability Distributions of Walking Distance

in Figs. 3–5, represent the proportion of people walking a distance shorter than the distance shown. Thus, the slope of the distribution at any given distance will give the number of the proportion of people that would be affected by a change in the walking distance. A closer examination of the rate at which the slope of the cumulative distribution is changing will enable one to determine the point at which this rate is maximum. At this maximum point, even a small change in walking distance will affect the greatest number of people, and is thus called the "critical" distance.

This critical distance can be easily derived with basic calculus. For example, as mentioned earlier, the walking distance distributions for most work-based trips follow a gamma distribution. Therefore, the slope of the cumulative distribution function $F(x)$ for some trip types will be the gamma distribution given by Eq. 1, when k is an integer:

$$\frac{dF(x)}{dx} = \frac{m^k x^{(k-1)} e^{-mx}}{(k-1)!} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

in which x = walking distance; and m and k are distribution parameters.

Since the objective is to determine the maximum rate of change of the slope, the second derivative of $F(x)$ must be considered.

$$\frac{d^2F(x)}{dx^2} = \frac{m^k(k-1)x^{k-2}e^{-mx} - x^{k-1}me^{-mx}}{(k-1)!} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

To obtain the value of x that will maximize Eq. 2, the stationary points must be evaluated by setting its derivative equal to zero and solving for x. This procedure gives

$$X = \frac{(k-1) \pm \sqrt{(k-1) - (k-1)(k-2)}}{m} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

As an example, consider the bus-to-work trips. The gamma distribution parameters for this trip type, as given in Table 6, are $m = 1/398.4$ and $k = 2.06$. These values yield 796 ft when rounded off to satisfy the criterion that k is an integer, i.e., $m = 1/398$ and $k = 2$, and substituted in Eq. 3. The critical distance is thus estimated at 796 ft (243 m)—marginally smaller than the average walking distance of 819 ft (250 m)—because of the simplification of the parameters to illustrate the basis for calculating the critical distance.

This procedure is applicable not only to walking distance distributions, when represented by probability distributions. The distribution may be some polynominal function. The basis is to determine the point at which the slope is changing most rapidly. Furthermore, one need not start with the cumulative distribution function. The cumulative function was chosen here in order to keep the mathematics simple. One could examine the probability distribution function to determine the critical distance.

With most forms of distributions, the critical distance will be less than or nearer the mean, and never as high as the 85th percentile.

The advantage of this probabilistic method is most evident when data are limited. According to Bayesian statistical decision theory, the form of the prior or initial distribution may be assumed by the designers, and parameters may be estimated based on personal experience or the little information available. When more information becomes available, it could be combined with the prior distribution parameters to obtain the updated or posterior distributions, which will be nearer the actual distribution (1). Until more information becomes available, one could derive the critical distance using assumed parameter values.

CONCLUSIONS

Transportation facilities, such as parking lots, bus stops, etc., should be located within acceptable walking distance from major generators, such as shops and offices. The acceptable walking distance will depend on factors such as trip type, trip purpose and time of day.

The distribution of walking distances related to each factor can be used as a guide for determining the acceptable walking distance for a given journey type. Instead of selecting an arbitrary value, the form of the distribution is used as the basis for evaluating the acceptable distance. The point at which the rate of change of the slope of the probability distribution of walking distance or a function of walking distance is greatest would be the critical distance, beyond which most people would be reluctant to walk.

The distribution most appropriate for a locational decision may be selected by the planner or the engineer, depending on trip type, trip purpose, time of day, or any other factor that may be significant to the facility. For example, the location of a new bus terminal will depend on the type of users or the trip purpose of the users. The critical distance would be lower if most users are employees in the area, than it would be if the majority of users were shoppers.

The usefulness of this approach is enhanced by its applicability when information is limited. Where the form of the distributions is unknown, probability theory can be used to estimate the acceptable range of walking distances and to determine the significance level for a chosen critical distance. This method accounts for people's needs and feelings because the distributions represent the propensity to walk; it contrasts approaches incorporating arbitrary values.

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APPENDIX II.—NOTATION

The following symbols are used in this paper:

$dF(x)/dx$ = first derivative of cumulative distribution function $F(x)$;
$d^2F(x)/dx^2$ = second derivative of cumulative distribution function $F(x)$;
$F(x)$ = cumulative distribution function of walking distances;
k = shape parameter of gamma distribution;
m = scaling parameter of gamma distribution; and
x = walking distance.

AN ANALYTICAL METHOD OF TRAFFIC FLOW USING AERIAL PHOTOGRAPHS

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(Reviewed by the Urban Transportation Division)

ABSTRACT: The outline and results of an aerial traffic survey of an 800-m section of the Hanshin Expressway are described. The objectives of the study were to record congested traffic flow and to determine its causes. Traffic in the study section was photographed by two 35-mm still cameras every 5 s for 1 h. All vehicles recorded in the southbound traffic flow were numbered and traced in order to project their trajectories in the time and space diagram. Speed and density contour diagrams were based on the theory of three-dimensional representation of traffic flow. The characteristics and causes of traffic congestion were analyzed using these diagrams.

INTRODUCTION

Traffic congestion on urban expressways is a daily occurrence in almost every major city in the world. This study deals with congestion in the outgoing traffic on the Hanshin Expressway in Osaka, Japan. Attention was focused on a bottleneck section of one of the six radial routes extending from the so-called Central Ring: Congestion extending upstream from this section into the Central Ring affects the function of the entire network. In order to clarify the mechanism of this congestion, a comprehensive traffic survey was conducted using a series of aerial photographs taken by helicopter, a video camera recording from the roadside, and travel time measurements from a floating test vehicle. The study section covers 800 m of the southbound lanes on the Sakai Line between the West Osaka junction and the Tsumori on-ramp.

OUTLINE OF TRAFFIC SURVEY

The location of the study section is shown in Fig. 1. Daily congestion starts somewhere in the section around 10:00 a.m., and extends upstream toward the Central Ring. The section was photographed in its entirety every 5 s with a 35 mm still camera from a helicopter hovering at an altitude of 750 m. The traffic flow was recorded by a video camera on the roadside in order to check the accuracy of the data reduction results derived from the aerial photographs. Also, a travel time survey was conducted using a floating test vehicle.

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